Convective Severe Weather

3a. Draw conclusions about convective severe weather phenomena.

Climatology

- Thunderstorms
  - Occur most frequently over the SE US
    - More frequent during the warm season
    - SE is favorable for air-mass thunderstorm
    - Primary reason
    - Abundant of moisture
    - Heating

Climatology

- A secondary area of thunderstorms occur over the Great plains
  - During the summer nights
  - Primary reasons
  - Low-level jet
  - Nocturnal cooling

Climatology

- Frontal thunderstorms
  - Affects the rest of the country
  - Occur year round

Climatology

- Severe thunderstorms/tornadoes
  - Geographical
    - Extends from Continental Divide to Appalachian Mountains; from the Gulf of Mexico to Canada
    - Tornado Alley (Northern Texas, Oklahoma, Kansas, Nebraska)

Climatology

- Seasonal
  - March through June for tornadoes
  - March through September for severe thunderstorms
  - Can occur anytime when conditions are favorable

Climatology

- Prefer a baroclinic state (warm moist air clashing with cool dry air)
  - cP (Canada) with mT (Gulf of Mexico) associated with the polar front
  - mT with cT (Mexico, SW US) associated with the dry line
- The occurrence of tornadoes decrease during the summer
  - Lack of dynamic
  - Low-level thermal contrast

Climatology

- Favored area shifts with the position of the PFJ
  - Winter- PFJ is over the Gulf States
  - Early Spring- PFJ is over the Southern Plains
  - Mid Spring- PFJ is over the Central Plains and Midwest
  - Late Spring and Summer- PFJ migrates over the Northern Plains and Great Lakes
- Tornadoes are faster and stronger during late winter and early spring (PFJ and low-level thermal gradient)
- Tornadoes are slower and weaker during late Spring and Summer (lack of PFJ and thermal gradient)

Climatology

- Diurnal
  - Prevalent during late afternoon / evening (max heating)
  - Early morning during the winter months along the Gulf Coast
    - Nocturnal cooling aloft
    - Times of maximum atmospheric instability

Climatology

- Heavy rain (no diurnal variation)
  - Summer
    - » Slow moving or stationary convective cells
    - » August-September: tropical cyclone
  - Winter
    - » Western coastal mountains
    - » Bombardment of moisture-laden storms

Climatology

- Flash flood
  - Defined as one that rises and falls quite rapidly with little or no warning usually as a result of intense rainfall over a relatively small area
  - Seasonal
    - » Warm season (April through September)
    - » July being the predominant month
  - Most flash flood events are nocturnal

Climatology

- Geographical
  - » Eastern US events are longer in duration
  - » Western US event are shorter in duration
- Synoptic characteristics
  - » Regenerative convective storms
  - » High dew-point temperatures
  - » Large moisture content through a deep tropospheric layer
  - » Weak-moderate vertical wind shear

Convective weather conditions

- Thunderstorms
  - Affects on ground operations:
    - Lightning
      - Stops refueling due to explosive hazard
      - Limits outside exposure to personnel
      - Possible power fluctuation (computers must use back-up power)

Convective weather conditions

- Strong surface winds
  - Winds speed < 50 knots will move unsecured objects around
  - Reduced visibilities due to blowing dust and dirt
  - Winds speed ≥ 50 knots will damage structural facilities
  - Winds speed ≥ 50 knots moves large aircraft around the flight line
  - Smaller objects may become projectiles

Convective weather conditions

- Hail
  - Hail < 3/4 inch
    - » Danger to personnel in exposed areas
    - » Damage weak structural
  - Hail ≥ 3/4 inch
    - » Seriously injure personnel in exposed areas
    - » Significantly damage exposed aircraft, vehicles and structures

Convective weather conditions

- Heavy rain $\geq$ 2 inches in 12 hours
  - 1 Flooding of low lying areas
  - 2 Reduces visibilities

Convective weather conditions

- Affects on aviation
  - Lightning
    - Cause aircraft electrical and structural damage
    - Probability of lightning located within ±5,000 feet of the freezing level

Convective weather conditions

- Turbulence
  - Experienced beneath, in clouds, and/or above the clouds
  - Usually moderate to extreme in intensity with thunderstorms
- Icing
  - Occur in very high moisture content i.e., cumulonimbus
  - Experience all types (clear, rime and mixed)
  - Accumulates faster than the removable capability of the de-icing equipment on the aircraft

Convective weather conditions

- Low-level wind shear (LLWS)
  - Aircraft gain/lose lift
  - Shear between the updrafts and downdrafts can range from severe to extreme
- Hail possibly $\geq$ 3/4 inch in diameter aloft

Convective weather conditions

- Safety of aircrews
  - Thunderstorms are hazardous
  - Thunderstorms causes pilots to deviate from their normal flight plans; consequently, aircraft will burn more fuel
  - Clouds may have an electrical charge well after thunderstorms had dissipated

Convective weather conditions

- Tornadic activity
  - Appearances
    - Funnel cloud
    - Tornado
    - Extending from the base of a CB cloud
    - Appear in the right rear quadrant of a CB (respect to movement)

Convective weather conditions

- Wall cloud
  - Where the inflow entering the updraft
  - Wall cloud usually represents the area of the updraft
  - Tornadoes form on the periphery of the wall cloud

Convective weather conditions

- Movement
  - Controlled by the motion of the parent storm
  - Average movement SW to NE
  - Average speed 30 mph

Convective weather conditions

- Smaller scale
  - Motion can be in any direction
  - circular pattern are often observed under parent cloud
  - Speeds from 0 to 70 mph have been observed

Convective weather conditions

- Wind Shear is the primary reason the tornado is so destructive
  - Speed
    - Calm winds are often observed before the onset
    - Matter of a few second, speeds go from 0 to 200 mph
  - Direction
    - Wind shift of 360□ of shear occurs in a matter of seconds
    - This type of shear will destroy a structure

Convective weather conditions

- Tornado look-alikes
  - Mammatus clouds sometimes believed to be initial stage of a tornado
    - Formed due to subsidence; quite harmless
    - Occur at all levels
    - Seen immediately after the passage of a violent storm

Convective weather conditions

- Roll clouds
  - Form along the advancing gust front
  - Exhibits rotation about a horizontal axis

Convective weather conditions

- Other Features that look like tornadoes
  - Ragged shelf clouds
  - Virga
  - Rain shaft
  - Although these features are not tornadoes, they can inflict damage

Convective dynamics

- Terminology
  - Lifted Condensation Level (LCL) is the height at which a parcel will become saturated when lifted by a mechanical force and clouds will begin to form when air becomes saturated and water vapor condenses
  - Convective Condensation Level (CCL) is the height at which a rising parcel becomes saturated when heated from below and rises adiabatically until saturation occurs
  - Environmental Temperature (ET) is the temperature of a sounding

Convective dynamics

- Positive Energy Area (PEA) is the are on a Skew-T Diagram that is proportional to the amount of kinetic energy a parcel gains as it rises freely in the atmosphere
- Level of Free Convection (LFC) is the height at which a lifted parcel of air becomes warmer, or less dense than the environment
- Equilibrium Level (EL) is the height at which the temperature of a positively buoyant parcel becomes equal to that of the environment

Convective dynamics

- CAPE (Convective Available Potential Energy) is defined as the positive energy available for storm growth

Convective dynamics

- Convective Scale Dynamics
  - 1 Ingredients for thunderstorm formation
    - **TR: Instability**
      - Instability is defined as a condition of the atmosphere where by a parcel of air is displaced upward from its origin
        - Atmosphere is considered to be conditionally unstable on thunderstorm days

Convective dynamics

- Causes
  - » Heating
  - » An increase in low-level moisture
  - » Cooling in the upper levels
  - » Evaporative conditions in mid/upper-level moisture

Convective dynamics

- Moisture
  - An increase in low-level moisture will modified
    - » CCL
    - » LCL
    - » LFC
  - Release of latent heat modified the atmosphere
    - » Slows the cooling rate of a rising parcel
    - » If the ascending rate of the parcel is less than the environmental lapse rate, the parcel will continue to rise

Convective dynamics

- Lift (trigger)
  - Synoptic scale lift
    - » Will **NOT** by itself trigger convection
    - » Creates an environment that is conducive for development
    - » Increases the lapse rate needed
    - » Examples
      a. Mid-and upper-level short-wave troughs
      b. Jet stream maxima
      c. Warm air advection

Convective dynamics

- Mesoscale Lift
  - » Causes the majority of thunderstorms in the US
  - » Low-level convergence
    a. Boundaries
    b. Topography
    c. Differential heating

Convective dynamics

- Exhaust
  - Upper-level divergence
  - Enhance the process

Convective dynamics

- Evolution of Thunderstorm
  - Cumulus stage
    - Marked by the formation of the first convective cloud
      - With its base at or slightly above the CCL, the cloud is dominated by updrafts as it grows toward its equilibrium level
      - As increasingly low-level moisture is pumped into the growing cumulus, relatively large liquid hydrometeors begin to form in its upper regions
      - From the outside, the cloud top may seem to lose definition as the cloud droplets turn to ice crystals

Convective dynamics

- This process appears to correlate well with the formation of precipitation
  - A radar echo aloft should now begin to appear
  - The updraft continues to hold the prospective precipitation aloft until it accumulates beyond the point at which its weight can be supported
  - It then falls against the updraft and begins to create a downdraft due to frictional drag

Convective dynamics

- Mature Stage
  - This stage is the most violent and active
    - Updrafts and downdrafts coexist in the same cell
    - The cloud reaches its maximum vertical extent, flattening out into the familiar anvil at the equilibrium level
    - Carried by the winds at that level, the anvil usually elongates downstream
    - Although heavy precipitation is common, it may not reach the surface in extremely arid regions

Convective dynamics

- Recall that precipitation drag is the primary downdraft mechanism
  - Although it would seem that the heavier the precipitation, the stronger the downdraft; however , this is not always so
  - In arid regions, violent downdrafts from clouds with high bases are common, but there is very little precipitation at the surface
  - An important factor here is the presence of dry air in the thunderstorm environment
  - If dry air enters the convective cloud, evaporation of cloud droplets takes place, with a corresponding drop in temperature

Convective dynamics

- This increases the density of the air and gives it a tendency to sink
- This process is thought to be a significant downdraft enhancement mechanism in nearly all thunderstorms
- It requires a delicate balance, because too much dry air would completely evaporate the cloud

Convective dynamics

- When the downdraft reaches the surface, it spreads out horizontally as a new air mass
  - The leading edge of this outflowing air is known as the “gust front,” or “outflow boundary ”
  - Surface winds shift drastically with the passage of a gust front; they can attain damaging speeds, depending on the strength of the downdraft
  - Aircraft are particularly vulnerable to these windshifts
  - Headwinds change into crosswinds or tailwinds in seconds to produce the deadly phenomenon known as “low-level wind shear”

Convective dynamics

- The updraft continues to hold precipitation aloft
  - Ice crystals suspended near the melting level alternate between freezing and melting, accumulating a water coating as they move up and down in and around the updraft core
  - The result is a hailstone, which continues to grow until it is too heavy to be supported by the updraft
  - Stronger updrafts can support larger hailstones
  - Once a hailstone falls below the freezing level, it begins to melt
  - It continues to melt until it reaches the surface, unless it melts completely first

Convective dynamics

- The height of the melting/freezing level is near the 0°C isotherm; the height of the wet-bulb zero, therefore, is significant in determining the size of a hailstone at the surface
- Miller (1972) reported that a wet-bulb freezing level of 7,000-9,000 feet AGL is the optimum height for producing large hail at the surface
- Although a lower wet-bulb freezing level may be favorable for hailstone survival, it may not be favorable for thunderstorm development because the air mass would be too cold

Convective dynamics

- Another product of updraft and downdraft interaction is turbulence
  - Many aircraft have been destroyed during attempts to penetrate thunderstorms
  - Even small thunderstorms, as observed from the surface, are capable of severe to extreme turbulence
  - Expect at least severe turbulence in and near any thunderstorm cell

Convective dynamics

- Dissipating stage
  - This stage begins when the updraft collapses
    - With gravity on its side, the downdraft soon dominates
    - Outflow air eventually cuts off the inflow of warm, moist air into the storm
    - With the moist inflow cut off and the updraft weakened, the precipitation process begins to shut down
    - Without a strong updraft, large hydrometeors can no longer form, leaving only light rain or drizzle and generally light winds at the surface
    - Although violent electrical activity usually ceases, the cloud can retain a charge and remain a hazard to aircraft for some time

Convective dynamics

- With subsidence prevailing, the cloud-forming process stops
  - The giant cumulonimbus begins to stratify into layered clouds and is eventually torn apart by winds aloft
  - At the surface, a large bubble of rain-cooled outflow air is left behind
  - Even though it is relatively stable, this bubble can play a role in future thunderstorm development due to convergence and lifting along its boundaries
  - The life cycle of a typical thunderstorm cell can be completed in as little as 30 minutes

Types of convective weather

- Terminology
  - Hodograph is a method of graphically displaying a vertical wind profile
  - Helicity measures the potential for rotation in the thunderstorm’s updraft

Types of convective weather

- Types of thunderstorms
  - Single-cell thunderstorms
    - Short-lived cells
      - Consisting of one updraft
      - Precipitation begins during the onset of the downdraft
      - Lasting from 30 to 60 minutes in duration
      - Severe weather is rare

Types of convective weather

- Environment
  - Occur in weak vertical shear
  - Move with the mean wind in the lowest 5 to 7 km
  - Hodograph displays an unorganized structure and randomly distributed points
  - On radar, precipitation can be first detected in the low and mid-level of the storm

Types of convective weather

- Pulse Severe Storm
  - Single cell storm that develops within a weakly sheared environment
    - » Relatively short-lived
    - » Severe weather events are brief
  - High winds and hail are possible but short-lived
  - Tornadoes are very infrequent

Types of convective weather

- Severity
  - Entirely dependent upon the potential instability
  - Large water droplet will be suspended aloft longer
  - Pushed higher because of the intensifying updraft because the faster the air rises, the less time for water droplet to coalesce into radar detectable echoes
  - First detectable echoes on radar will appear in the mid- to upper-level
    - » Develops higher than the non-severe single cell storms
    - » Remain aloft longer than non-severe single cell storms

Types of convective weather

- Multi-cell thunderstorms
  - These storms require a much greater degree of instability and more time to develop to severe limits
    - The updrafts must remain active and unimpeded
    - Precipitation forming in the middle and upper portions of the updraft core must not fall back through the updraft
    - If strong mid-level winds are present at 20,000 and 30,000 feet, they carry the precipitation so far downstream that they do not fall into the updraft

Types of convective weather

- A downdraft (completely separate from the updraft) forms in conjunction with the precipitation in the forward portion of the storm
- In addition to being cleared of obstructions, the updraft intensifies beneath mid-level winds
- This occurs as updraft draws mass from below, through an action similar to the suction effect of a paint sprayer

Types of convective weather

- With the updraft increasing in intensity, the storm grows larger
  - The momentum of the high-speed updraft carries mass far above the EL (sometimes by several thousand feet), resulting in a cumuliform dome that overshoots the cirrus anvil deck
  - At lower levels, the storm inflow is blocked from entering at the front of the storm by the rainy downdraft and its associated outflow
  - The presence of southerly low-level winds results in the storm drawing air from its right flank
  - This allows the swelling cell to take advantage of the warm, moist flow that help force the updraft

Types of convective weather

- Because it is dynamically supported from above and below, the updraft is strong enough to push the hydrometeors up and out of its way
  - This creates a cavity on the right flank of the storm (relative to storm motion) that is observable on radar as a “weak echo region” or WER
  - The mid-level overhang is over the WER on the right flank of the storm

Types of convective weather

- When the updraft reaches its maximum intensity, it is capable of producing 3/4-inch hailstones
  - The largest hail will fall just to the left and downstream of the updraft core, relative to storm motion
  - The largest stones will fall out of (or through) the updraft first, while the smaller ones are carried farther downstream by the strong winds aloft

Types of convective weather

- When the outflow from the rainy downdraft pushes against the inflow on the right flank, low-level convergence and lifting occurs
  - This is a favored location for new cell development
  - Often, a line of increasingly larger cumulus towers are observed building into the right flank of the storm
  - These flanking line cells eventually merge with the parent thunderstorm cell
  - When the new cells continue to form on the right flank and develop into mature storms, they give the impression that the storm is traveling somewhat to the right of its expected path

Types of convective weather

- We identified this type of movement as discrete propagation, it has been associated with radar interpretation as an indication of possible severe weather
- Individual cells generally move with the winds aloft
- As older cells move downstream, newer ones take their place on the southern flank
- The result is that there is always more than one cell in existence at a time in the storm complex, hence, the multicell storm

Types of convective weather

- Multicell storms last a long time due to their ability to renew themselves with new cell growth
- If these storms move slowly, persistent heavy rainfall may produce flash flooding

Types of convective weather

- The average shear value in the cloud-bearing layer is about 5 knots per km of depth
  - On a hodograph, a multicell is characterized by a straight line or unidirectional shear
  - Multicell severe thunderstorms may show stronger shear (up to 15 knots/km)

Types of convective weather

- Supercell
  - Three types of supercell
    - Classic Supercell is more common in the Plains States
      - » Possess the classic “hook echo or Bounded weak echo Region (BWER)
      - » Strong reflectivities in the upper level

Types of convective weather

» Low-level echo

a. Shows an inflow notch

b. Pendant or hook shape at the back side

c. Notch is surrounded by strong reflectivity gradient

» These storms are frequent producers of tornadoes, large hail and strong winds

Types of convective weather

- Low-Precipitation Supercell
  - » Most common along dry-line of western Texas
  - » Smaller in diameter than the classic super-cell
  - » Capable of producing large hail and tornadoes

Types of convective weather

- High-Precipitation supercell
  - » Common the farther east one goes from the Plains
  - » Produce heavier amounts of rain than the classic supercells
  - » Not as isolated as the other two types
  - » Capable of producing tornadoes and large hail

Types of convective weather

- Primary features are the Rear Flank Downdraft, BWER, and Mesocyclone
  - Structural
    - » Atmosphere
      1. Extremely unstable
         a. A favorable wind configuration so that the updraft can intensify still further.
         b. The ideal situation would be for winds to increase and veer with height.

Types of convective weather

2. A strongly sheared wind environment also contributed to separating the updraft and downdraft and to strengthening the storm.

a. With southerly winds in the lower levels and with westerly winds aloft transport cooler and often drier air aloft.

b. This kind of differential advection serves to further destabilize the environment while maintaining the unstable conditions.

Types of convective weather

c. Investigations by Marwitz (1972) and Doswell and Lemon (1979) show that pronounced veering (50°) in below cloud (subcloud) layer appears to be critical for creating a supercell formation from a multicell system.

d. They also found that supercell subcloud wind speeds were higher (at 10 m/sec) than the 8 m/sec found in the multicell systems.

e. The dynamic reasoning for this is elusive, but its conceivable that the strong subcloud winds act to force the updraft by ramming warm, moist air into the inflow flank of the storm.

Types of convective weather

» As the updraft intensifies further, it becomes more upright than in lesser thunderstorms because it is now strong enough to overcome the shearing effects of upper-level winds

a. So much mass is carried aloft by the updraft that it diverges in all directions, even upstream against the upper-level winds

b. This creates a sharp backsheared (upwind) anvil edge that is easily recognizable in satellite imagery

c. To compensate for all the mass being forced aloft, subsidence takes place outside the cloud, resulting in the suppression of surrounding convective activity

Types of convective weather

d. Any nearby convective cells are eventually obliterated as the dominant cell starves them of their warm, moist air to feed its own voracious updraft

e. The result is one powerful cell in control of its environment-- supercell

Types of convective weather

» Intense updraft causes a change in the configuration of the WER

a. Because of the high speeds, precipitation forms higher within the updraft and results in the creation of a cavity in the mid-level radar echo overhang

b. The WER now extends into the mid-level overhang, creating what is known as a “bounded weak echo region” or BWER

c. The updraft region is “bounded” by higher radar returns and is indicative of a very strong updraft

d. An updraft of this magnitude can produce even larger hailstones ($\geq$ 2 inch) than a multicell updraft, and the “steadier state” of the supercell results in a longer hail swath at the surface

Types of convective weather

» The updraft in supercell thunderstorms almost always rotates about a vertical axis

a. The source of rotation involves the tilting of vorticity fields

Along the outflow boundary, strong anticyclonic shear is produced between inflow and outflow

b. The horizontal roll cloud that often forms ahead of strong thunderstorms is vivid evidence that shear exists

c. Along the right flank of the thunderstorm cell, some of this shear may be drawn into the intense updraft

Types of convective weather

d. When the anticyclonic vorticity field is tilted upward, it is oriented about a vertical axis and, if viewed from above, is cyclonic

e. The updraft is then induced to rotate cyclonically about a vertical axis and, if stretched in the vertical, rotates faster (helecity)

f. The rotating updraft is referred to as the mesocyclone in its “organizing stage ”

g. This scenario is quite possible, without the presence of an outflow boundary, in areas where winds speeds increase rapidly above the surface to produce vertical speed shear

Types of convective weather

» The rotation of the updraft

a. It has a pronounced effect on the structure and behavior of a supercell

b. The circulation pulls precipitation around the backside of the updraft core, creating a pendant-like protrusion on the right rear quadrant of the low-level radar echo

Types of convective weather

- The strong swirling inflow draws warm, moist surface air upward, resulting in a lower condensation level (and therefore a lower cloud base) where the inflow (updraft) enters the cloud base

    a. This feature, known as a “wall cloud”, frequently shows rotation

    b. At this stage, the updraft is at its maximum strength

    c. The storm top is at its highest extent, directly over the updraft core

    d. Hail is at its largest, falling to the left and somewhat ahead of the wall cloud

    e. Funnel clouds are common, and weak tornadoes may touch down briefly

Types of convective weather

» In the mid-levels of the storm, the rotating updraft effectively obstructs horizontal wind flow

a. As the winds split around the rotating updraft core, they converge with the circulation on the left side, resulting in a mass buildup and a subsequent pressure excess to the left of the updraft core

b. On the right side, they travel with each other, resulting in a relative pressure deficit

c. In order to correct the pressure imbalance, the updraft core is forced to shift to the right, toward lower pressure

Types of convective weather

d. Where the updraft goes, the storm must follow

e. The result is a supercell that deviates to the right of the mean upper-level winds flow

f. This principle of fluid dynamics is termed “Magnus Effect”

g. As upper flow splits around the rotating updraft, a pressure imbalance is created

h. This forces the updraft core to deviate to the right of the original path and causes the storm to move to the right of the upper winds

Types of convective weather

» Pressure increases under the upwind edge of the anvil when strong mid-level flow piles up against the rear of a rotating updraft core as seen in

a. As the mass increases, subsidence begins

b. The subsidence is enhanced by the evaporational cooling that takes place when drier mid-level air erodes the backside of the storm clouds

c. Subsidence tends to channel mid-level flow downward, creating a dynamic downdraft in the rear of the storm

d. This “rear flank downdraft” (RFD) is in addition to a precipitation-induced “forward flank downdraft” (FFD)

Types of convective weather

e. As the RFD intensifies, it begins to deform the updraft, and a cyclonic shear zone forms at the updraft/RFD interface in the middle levels of the storm

f. At this stage, the mesocyclone center moves near the interface and is divided between the updraft and the RFD

g. It’s usually evident in the radial velocity display of Doppler radar as a tight positive/negative velocity gradient

Types of convective weather

» As the RFD gains strength, the mesocyclone (now in the mature stage) extends through a deep layer as it is stretched downward

a. The vertical stretching results in further intensification and a decrease in diameter

b. This small, intense velocity gradient is called the “tornado vortex signature,” or TVS

c. As the RFD reaches the surface and spreads out and around the right side of the updraft (the updraft circulation offers the least resistance on its right side), the RFD air advances eastward as a new gust front

d. The meso-cyclonic circulation is pulled down by the RFD until it reaches the surface as a tornado

Types of convective weather

» As the RFD continues to spread, the low-level pendant is deformed into the more familiar hook shape

a. The hook itself is precipitation caught in the advancing RFD air, and may contain damaging straight-line winds

b. The open, or echo-free area is the updraft core (the BWER in the horizontal plane)

c. The tornado is typically found on the interface between the RFD and the updraft, which is a strong cyclonic zone near the tip of the hook

Types of convective weather

» The action of the RFD eventually takes it toll on the updraft

a. As the updraft weakens due to the drag of the RFD, there is a drop in the storm top

b. This is consistent with Lemon's finding (1980) of BWER collapse at the time of major tornado production

c. Eventually the updraft collapses entirely under the domination of the RFD; when it does, tornado activity stops

d. The RFD vs updraft battle, however, may go on for hours, producing long-track tornadoes

A new updraft may form at the occlusion of the storm-scale fronts, and the cycle may begins again

Types of convective weather

- A curved hodograph indicates strong directional and speed shear in the lower 3 km of the sounding
- A mean storm inflow speed of 20 knots is needed for supercell development

Types of convective weather

- Splitting Cells
  - Occasionally a super-cell will split into two separate cells
    - » Right cell
    - » Left cell
  - Causes
    - » Environmental wake flow
    - » Water loading

Types of convective weather

- Right cell
  - » Often intensifies
  - » Deviates about 30° to the right
  - » A potential tornado producer
- Left cell
  - » Often weakens
  - » Deviates about 50° to the left and accelerates
  - » Good hail producer and tornadoes are rare

Types of convective weather

- Squall lines
  - It is a line of thunderstorms that is NOT readily circumnavigable
    - May or may not be associated with a wind shift line or front
    - Normally occur 50 to 300 miles ahead of an inactive front
  - Facts
    - Commonly a high wind producer
    - Hail and tornadoes are possible
    - Not all squall lines produce severe weather

Types of convective weather

- Structural
  - Updrafts normally enter from the front of the squall line
  - Updrafts tilt vertically due to speed shear
  - Evaporational cooling and precipitational drag will initiate the downdraft behind the updraft

Types of convective weather

- Down rushing winds from the downdrafts will forces the out flow ahead of the line
  - » Resulting in low-level convergence
  - » Regeneration of new updraft
- Squall line continues to propagate forward
- Developing at the southern flank end of the line

Types of convective weather

- Environment
  - Hodograph depicts a straight line
  - Indicating strong speed shear
  - Winds speeds rapidly increasing to 60 knots or higher

Types of convective weather

- Decaying process
  - Squall lines carry the seed of their destruction
    - » Line moves away from where it originates
    - » Associated activity continually cools the low levels
    - » Windshifts and significant pressure rises move out ahead of the thunderstorms
    - » Resulting in the death of the squall line

Types of convective weather

- Often takes on quasi-stationary frontal characteristics
  - » Rain cooled air on one side and mT air on the other side
  - » Squall line passage is often confused with frontal passage
  - » Rain-cooled air-mass will often recover it’s original charecteristics after squall line passage
  - » Dew points are good indicators

Types of convective weather

- Mesoscale Convective Complex
  - Large, persistent and active convective weather system
    - Capable of producing the following
      - » Locally heavy rainfall
      - » Flash floods
      - » Tornadoes
      - » Hail
      - » Damaging winds
      - » Dangerous lightning

Types of convective weather

- Nearly circular in organization
- Must persist $\geq$ 6 hours
- Average lifetime $\geq$ 12 hours

Types of convective weather

- IR satellite characteristics
  - Exterior cloud shield with continuously low IR temperatures (<-32□C) covering an area > 100,000 km□
  - Interior cold cloud region with temperature (<-52□C) covering an area > 50,000 km□

Types of convective weather

- Four life cycles stages
  - Genesis Stage
    - » Number of individual thunderstorms develop within a region where the atmosphere is prime for convection
    - » Latent heat released produces a region of warming
    - » Entrainment of potentially cool environmental air producing evaporational driven downdrafts
    - » Allows for the development of outflow boundary with associated meso-high pressure system

Types of convective weather

- Development Stage
  - » Gust front and outflow from individual storm merge together producing a large outflow boundary
  - » Outflow boundary converges with the moist unstable air
  - » Region incorporated a mean meso-scale ascent and becomes saturated
  - » Exhibits a moist adiabatic lapse rate with a warm core system (compared with the surrounding environment)
  - » Movement tends to be with the 700-mb and 500-mb mean flow

Types of convective weather

- Mature stage
  - » Intense convective cells continue to form where the low-level flow feeds the system
  - » Severe weather may still occur
  - » Primary type of significant weather is locally heavy rain and gusty winds
  - » Flash floods are common

Types of convective weather

- Dissipating Stage
  - » Marked by a rapid change in the character of the MCC
  - » Begins when intense convective elements no longer develop
  - » System’s energy supply has been cut-off or modified due to the ingestion of dry stable air
  - » Outflow boundaries must be monitor for redevelopment of new convection

Types of convective weather

- Downbursts and Microbursts
  - Downburst
    - Strong concentrated downdraft
    - Potential for producing damaging surface winds reaching 40 knots
    - Downbursts are often found behind the gust front
    - Appear to be a form of the RFD

Types of convective weather

- Microburst
  - Concentrated downburst
  - Tornado-like damage equal to F3 on the Fujita Scale
  - Associated with a change in velocity of 50 knots or greater
  - Damage from straight-line winds and tornado-like vortices along the leading edge can inflict damage

Types of convective weather

- Three types of microburst
  - » Wet microburst
    - a. Found in a moist environment (Gulf Coast)
    - b. Convection develops in a surface -based moist layer and builds into or through a dry layer aloft
    - c. Entrainment of dry air
    - d. Evaporational cooling results and produces an area of negatively buoyant air
    - e. Precipitation drag also contributes to the downward acceleration

Types of convective weather

» Dry microburst

a. Found in a dry environment (SW US)

b. High-based clouds form above a deep surface-based dry layer

c. Precipitation falls into the dry layer and evaporates

d. Process requires latent heat

e. Negatively buoyant air accelerate downward

Types of convective weather

f. As long as precipitation is available, the downward path tends to follow a saturation adiabat

g. Once all precipitation evaporates, momentum will descend along the dry adiabat

h. Downward acceleration will continue as long as the descending air is cooler than the surrounding environment

Types of convective weather

» Hybrid microburst

a. Found in an environment that is changing from wet to dry or dry to wet

b. Depth of the sub-cloud layer with dry adiabatic lapse rate increases

c. Cloud bases rises

d. Depth of the mid-level moist layer diminishes

e. Changes result in less sub-cloud evaporation and more rainfall reaching the surface

f. Graupel and hail are possible along with strong winds

Convective Air masses and Synoptic Patterns

- Severe Weather Air Masses
  - Type I Air Mass (Great Plain, loaded gun, lid sounding)
  - Configuration
    - Composed of mT air in the low-level with mP or cP air aloft
    - Inversion presents above the moist layer (lid)
      - » Prevents the release of convection
      - » Moisture advection beneath the inversion creating a very unstable situation

Convective Air masses and Synoptic Patterns

- Winds increase and veer with height
  - » Veering maximizes differential air mass advection
  - » Strong winds aloft provide the exhaust mechanism
- Stability indices work well with the Type I air mass (average LI is -6)

Convective Air masses and Synoptic Patterns

- Activity
  - » Low-level heating, mechanical lifting, and evaporational cooling of cloud tops will break the inversion, resulting in the release of the unstable air
  - » Severe thunderstorms, which are widespread violent, long lasting, and develop rapidly
  - » Tornadoes are most common with Type I air mass

Convective Air masses and Synoptic Patterns

- Type II Air Mass
  - Configuration
    - mT- Moist at all levels No Inversion
    - Surface temperatures > 80□ F
    - Winds normally decrease with height (lack of synoptic systems) and strong winds aloft will enhance the activity
    - Stability indices work well with the Type II air mass (avg LI is -6)

Convective Air masses and Synoptic Patterns

- Activity
  - Good thunderstorm producer, but marginal severe weather producer due to the lack of strong dynamics
  - Tornadoes are relatively rare and have short and narrow paths
  - Hail is rare due to high wet bulb freezing level and lack of dry air
  - Hail may be found aloft

Convective Air masses and Synoptic Patterns

- Type III Air Mass (Cold Core)
  - Configuration
    - Relatively cool mP air in the low levels (50-70°F) and very cold air aloft (-25 to -35°C)
    - Moist throughout the air mass (avg RH > 70%)
    - Winds increase with height, but veering is not as prominent which is often found with a vertically stacked system
    - TT works well due to cold 500-mb temperatures LI and SSI do not work well due to low temperatures and dewpoints in the low-levels

Convective Air masses and Synoptic Patterns

- Activity
  - Thunderstorms develop in the mP air to the rear of well occluded system, in the dry slot
  - Low-level surface heating or warm water surface temperature are essential
  - Activity dies after sunset (except over water)
  - Hail is very common due to low freezing level
  - Funnel clouds (cold air funnels) are common with occasional brief touchdowns

Convective Air masses and Synoptic Patterns

- Type IV Air Mass (Inverted V)
  - Configuration
    - Hot, dry (cT air) in low-levels with cool, moist (mP) air aloft
    - Found in arid regions and on the lee-side of the Rockies
    - No particular wind configuration
    - Stability indices are not representative due to the lack of low-level moisture

Convective Air masses and Synoptic Patterns

- Activity
  - Surface heating and low-level convergence trigger the activity
  - Hail and damaging downrush winds (downbursts) are common due to the availability of low- and mid-level dry air (surface-700 mb)
  - Although rare, short-lived, and relatively weak, converging downbursts can produce tornado-like vortices
  - The presence of virga is a good indicator of possible downburst activity

Convective Air masses and Synoptic Patterns

- Evolution of Deep Convection - Synoptic Scale
  - General conditions
    - Strong, narrow band of winds aloft (300-mb) with a magnitude > 50 knots
    - Relatively strong, narrow band of winds exists between 700 mb and 500 mb with a magnitude > 35 knots
    - Distinct tongue of dry air in the mid or lower levels approaching from the west-southwest

Convective Air masses and Synoptic Patterns

- Low-level moisture ridge or tongue approaching from the south-southwest with a tight moisture gradient on the windward side
- Primary activity develops where the dry air intrudes into or over the low-level moisture ridge
- Trigger or lifting mechanism to release the convective instability

Convective Air masses and Synoptic Patterns

- Severe weather synoptic patterns
  - Type A - Dryline
    - Features and characteristics
      - Common in western Texas, Oklahoma, and Kansas
      - Well defined southeasterly flow of moist air from the Gulf of Mexico (Sfc to 850mb)
      - Well defined west-southwesterly flow of dry air at the low- and mid-levels positioned upstream from the low-level moisture ridge
      - Well defined west-southwest maximum wind band aloft (500-300 mb)

Convective Air masses and Synoptic Patterns

- There’s considerable convergence along the boundary between the moist SE flow and the dry SW flow of air
- Speed convergence is also commonly found upstream from the dryline in the dry air
- Often associated with a pressure trough and/or windshift line, although neither is necessary for existence
- Vertically, the dry air exhibits a nearly dry adiabatic lapse rate, while an inversion “caps” the moist air
- Normally associated with a Type I air mass

Convective Air masses and Synoptic Patterns

- Location Techniques
  - To locate the dryline it’s necessary to use a moisture variable
  - For Analysis of the dryline, the 9 g/kg isohume (mixing ratio) or the 55□ F isodrosotherm is recommended as the first estimation
  - Satellite imagery can also be used to help locate the dryline
  - Radar shows a linear area of increased spectrum values on the WSR-88D gives good placement on the dryline

Convective Air masses and Synoptic Patterns

- Movement
  - Daytime movement of the dryline is generally much faster than advection would support
  - One mechanism that accounts for this rapid movement is vertical turbulent mixing of moist, surface air with dry air aloft
  - After sunrise, boundary layer mixing starts as surface temperatures rise in response to insolation
  - West of the dryline, a nocturnal radiational inversion is rapidly replaced by a surface layer with an adiabatic lapse rate
  - Any moisture trapped beneath the inversion would be freely mixed in the dry air aloft

Convective Air masses and Synoptic Patterns

- The greater the depth of the moist layer, the greater the degree of heating required to break the capping inversion
- Since the general terrain of the southern plains slopes downward to the east, the depth of the moist layer also increases eastward from the dryline location
- Surface dewpoint temperatures drop rapidly, and the dryline “leaps” eastward to a position where no appreciable mixing between the air-masses has occurred
- Dryline bulges often form due to enhanced dry air advection driven by excessive winds in the dry air, and the vertical mixing of high momentum mid-level air to the surface

Convective Air masses and Synoptic Patterns

- Enhanced convergence occurs at the bulge
- Use the 700-mb winds to forecast probable location of dryline bulge formation
- Late Afternoon and evening, dry air cools rapidly
- Nocturnal inversion forms west of the dryline
- Inhibition of the vertical mixing of momentum leads to a decrease of the low-level winds in the dry air

Convective Air masses and Synoptic Patterns

- East of the dry line, strong easterly flow continues resulting in a net easterly wind across the dryline
- The dryline is advected westward by these winds
- Entire diurnal process will reoccur the next day

Convective Air masses and Synoptic Patterns

- Threat Area
  - Most violent activity occurs in the zone of maximum convergence at and just downstream (NE) of the dryline bulge
  - The magnitude of convergence, and the contrast between the dry and moist air is directly related to thunderstorm intensity
  - Maximum convergence usually does not materialize until late afternoon
  - Forced convergence (speed) is also important during the nocturnal retreat of the dryline

Convective Air masses and Synoptic Patterns

- The presence of an upper-level short-wave trough above the area of maximum convergence will increase the threat of severe weather
- Convergence will further be enhanced where intersecting boundaries meet
- The severe weather threat is greatest at the point of intersection
- Severe weather threat area extends from the 500-mb maximum wind band to about 200 nm to the right of this band
- Downstream limits will be the maximum eastward displacement of the surface dryline where the air mass remains unstable

Convective Air masses and Synoptic Patterns

- Activity
  - Thunderstorms form in clusters or lines along the dry line
  - Most violent thunderstorms will occur at intersection points between the dryline and other boundary
  - Large hail, damaging winds, powerful and long-lasting tornadoes are common
  - Activity is mainly limited to the late afternoon and early evening
  - Severe thunderstorms can develop along the dryline during its nocturnal retreat

Convective Air masses and Synoptic Patterns

- Type B - Frontal
  - Features
    - A well defined flow of moist air at the low-level (this may be in the form of the low-level jet or a maximum wind band)
    - A well developed surface baroclinic low with associated cold and warm fronts
    - Dry air behind the cold front is most favorable
    - A well-defined mid-level (700 mb) dry air intrusion from the west-southwest

Convective Air masses and Synoptic Patterns

- A well-defined southwesterly maximum wind band aloft (500 mb-300 mb) with a major upper-level trough (with embedded short wave) to the west
- A capping inversion will exist above the warm, moist, low-level air (type I air mass)

Convective Air masses and Synoptic Patterns

- Threat area
  - Frontal or prefrontal deep convection (squall line) forms when the surface cold front (or short wave) enters the unstable air mass
  - Typically, severe storms first break out somewhere near the intersection of the PFJ (500 mb - 300 mb max wind band) and low-level jet (850 mb max wind band)
  - Look for areas where the low-level (850 mb) thermal ridge intersects the moisture ridge
  - This is the area where the greatest warm air and moisture advection is taking place

Convective Air masses and Synoptic Patterns

- Greatest threat area is from the 500-mb maximum wind band (left front quadrant of PFJ axis) to about 200 nm to the right of the axis
- This area correlates to the PFJ and LLJ intersection to 200 nm south of the intersection
- The threat area can also extend north of the intersection
- If a subtropical jet is present, upper-level divergence between the two upper jets is enhanced and storms that develop in this area become particularly intense

Convective Air masses and Synoptic Patterns

- The downstream boundary of the threat area is where the air mass is no longer unstable enough to support severe convection
- Cold frontal passage completely clears the threat area

Convective Air masses and Synoptic Patterns

- Activity
  - The most violent activity occurs where a squall line intersects a warm front or outflow boundary (meso-low and LEWP formation)
  - Activity mainly occurs during late afternoon and early evening (max heating time), but can occur at any hour
  - Large hail, damaging winds, and violent, long-lasting tornado families are common
  - Type B synoptic pattern is responsible for the major tornado outbreaks

Convective Air masses and Synoptic Patterns

- Type C - Overrunning
  - Features
    - Warm, moist, unstable air overrunning a stationary or warm front in the low levels (850 mb)
    - Strongest overrunning occurs where the 850-mb maximum wind band (low-level jet) intersects the frontal boundary
    - A well-defined westerly maximum wind band aloft (500 mb - 300 mb), north of, and parallel to the frontal boundary

Convective Air masses and Synoptic Patterns

- A well defined mid-level (700 mb) dry air intrusion from the southwest, located upstream of the area of strongest overrunning
- Stability indices work fairly well, but may not show potential the air mass has to support convection due to cooler low-level air north of the front

Convective Air masses and Synoptic Patterns

- Threat area
  - The main threat area is between the front and the 500-mb max wind band where the strongest overrunning is taking place
  - The presence of a short wave propagating through this area will enhance storm severity
  - The upstream boundary is approximately 50 nm west of the area of maximum overrunning
  - This corresponds to the leading edge (nose) of the 700-mb dry air intrusion
  - The downstream boundary is difficult to determine The only indication is the lack of sufficiently unstable air (use stability index analysis)

Convective Air masses and Synoptic Patterns

- Activity
  - Thunderstorms will remain below severe limits until the mid-level dry air intrudes into the threat area
  - A squall line will frequently form along the leading edge of the dry air
  - The squall line will be the bubble type with a strong gust front (outflow boundary) at the leading edge
  - A well defined meso-high will be left in its wake
  - Hail is common due to the low freezing level

Convective Air masses and Synoptic Patterns

- Strong, gusty winds will occur with the passage of the gust front
- Tornadoes are not common due to the cool air at the surface, although they can occur
- Activity is strongest during maximum heating but can occur at any hour

Convective Air masses and Synoptic Patterns

- Type D - Cold Core
  - Features
    - Cool mP at the low levels with a well-defined cold pool aloft (500mb)
    - A well-defined upper-level (500 mb) closed system with an associated occluded surface low and the system is nearly vertically stacked
    - Relatively clear skies are located behind the mP front in the dry slot

Convective Air masses and Synoptic Patterns

- Low-level convergence and, in the strongest cases, a low- and mid-level dry air intrusion upstream from the low-level convergence
- Air mass (Type III) will show maximum potential by using the total totals index (TT reacts to 500-mb cold pool)

Convective Air masses and Synoptic Patterns

- Threat Area
  - Main threat is usually confined to the area beneath the cold pool, in the area of the most unstable air
  - With surface heating being the major trigger, this must be an area of relatively clear skies
  - Most intense activity will occur in the zone of maximum convergence, especially if the dry air intrusion enters the area

Convective Air masses and Synoptic Patterns

- Activity
  - Intense thunderstorms form shortly after noon and normally dissipate at sunset
  - Funnel clouds (cold air funnels) are common with brief, but occasional tornado touchdowns
  - Hail is very common due to the low freezing level
  - Hail normally increases in quantity and size near the cold core

Convective Air masses and Synoptic Patterns

- Type E - Major Cyclone
  - Features
    - A major occluded cyclone
    - Strong, low-level (850 mb) overrunning of warm, moist, unstable air over a surface warm front
    - A well-defined mid-level, dry intrusion, along with strong cold air advection located upstream of the strong overrunning
    - Again, stability indices will not show full potential of air mass to support convection due to the cool low-level air north of the warm front

Convective Air masses and Synoptic Patterns

- Threat Area
  - The main threat area is located north of the warm front where the strongest overrunning is taking place, northward to the 500-mb maximum wind band
  - The threat area may extend left of the maximum wind band
  - The upstream boundary will either be the position of the occlusion or the 700-mb dry air intrusion, whichever is farthest east
  - The downstream limit is where the air mass is no longer unstable enough to support severe convection

Convective Air masses and Synoptic Patterns

- Activity
  - Activity becomes severe when the dry air intrusion and cold-air advection enter the threat area
  - Hail is the most common severe weather phenomenon, although tornadoes do occur with moderate frequency
  - Activity is strongest during maximum heating time, but can occur at any hour
  - This type often forms in conjunction with a Type B or Type C outbreak

Convective Air masses and Synoptic Patterns

- Evolution of Deep Convection (mesoscale)
  - In general, it appears that severe weather occurs in narrow bands of activity rather than at random locations throughout the threat area
    - Narrow corridors correspond to paths of intersections between lines of discontinuities (boundaries)

- Discontinuity lines
  - Warm or stationary fronts
  - Cold fronts
  - Drylines
  - Squall lines
  - Sea breeze/lake breeze fronts
  - Thunderstorm outflow boundaries

Convective Air masses and Synoptic Patterns

- Boundary interaction - general
  - Each of the above boundaries acts as a line of low-level convergence
  - If these boundaries intersect, the convergence is magnified at this point
  - As a result, upward vertical motions are magnified at this point
  - If the air mass is unstable, convection will most likely erupt at this intersection point

Convective Air masses and Synoptic Patterns

- The intensity (severity) of the convection will be determined by the degree of instability and the upper-level dynamic support (presence of a short wave)
- As the active boundary continues to advance, the point of intersection will also advance, along the dormant boundary
- The intense convection will continuously redevelop at the intersection, giving the impression of an abnormal movement
- If the synoptic situation is favorable, severe weather (particularly tornadoes) will break out at the intersection

Convective Air masses and Synoptic Patterns

- Most severe weather reports will be confined to a narrow corridor along and to the left of or on the cold side of, the dormant boundary
- The dormant boundary may be a source of rotation for the updraft
  - Entrainment of the vorticity field (vorticity max) around the boundary by the updraft will initiate rotation
  - Anticyclonic roll (horizontal axis) due to vertical speed shear will become cyclonic (vertical axis) if tilted upward by entrainment into the updraft, resulting in rotation of the updraft

Convective Air masses and Synoptic Patterns

- Boundary interaction - examples
  - Squall line intersecting a warm front - the most significant tornado producer
    - Wind flow characteristics around the warm front:
      - » Low-level convergence at the frontal boundary
      - » Cyclonic windshift across the frontal boundary
    - Strong, low-level convergence with the squall line
    - As the squall line intersects the warm front, the two convergence regimes couple

Convective Air masses and Synoptic Patterns

- This results in much stronger convergence and upward vertical motion at this point
- Convection will intensify dramatically at the intersection and severe weather is likely as the updraft intensifies
- Lower pressure forms due to the intense upward vertical motion, resulting in the formation of a meso-low
- Cyclonic rotation forms due to the circulation around the meso-low and the cyclonic vorticity field already present along the front

Convective Air masses and Synoptic Patterns

- The squall line will frequently wave at this point due to the cyclonic circulation
- This wave is referred to as a line echo wave pattern (LEWP)
- The entrainment of cyclonic vorticity into the updraft makes the cell at the intersection a dangerous tornado producer
- As the squall line moves along the warm front, intense convection continues to form at the intersection point
- Severe weather will continue to occur along this path as long as the air mass remains unstable
- The path of the intersection point will be altered as the warm front also advances

Convective Air masses and Synoptic Patterns

- Cold front / dryline / squall line intersecting an old thunderstorm outflow boundary
  - Earlier thunderstorm activity that has since dissipated will leave a trail of outflow air (outflow boundary) in its wake and this boundary will spread out in all directions
    - » The southern edge of the outflow boundary will become better defined due to the low-level convergence between the synoptic scale southerly flow and the cooler outflow air (usually from the NE)
    - » The outflow boundary will act very much like a mesoscale front

Convective Air masses and Synoptic Patterns

- As the outflow boundary continues to propagate, it will begin to lose its visible definition, but it is still very much a significant boundary
- The outflow boundary will usually persist until the air mass changes due to frontal passage, or nocturnal cooling stabilizes the entire region
- The outflow boundary can persist for over 12 hours and cover an area over 3000 nm
- Visible satellite imagery is the best tool available to determine the location of the outflow boundary
- A thin line of cumulus clouds will outline the outflow boundary (arc cloud)

Convective Air masses and Synoptic Patterns

- Severe convection will occur when the cold front / dryline / squall line intersects the outflow boundary Similar to the squall line / warm front intersection
- Due to the difficulty of locating outflow boundaries, this type of intersection is more difficult to detect
  - » Monitor all thunderstorm activity Carefully consider outflow boundaries with all thunderstorms
  - » Carefully analyze all surface and satellite data to help locate outflow boundaries
  - » **CONTINUITY!** Pass on all boundary locations to next forecaster

Convective Air masses and Synoptic Patterns

- Intersection of two outflow boundaries
  - » Basically the same effect as previous cases, but resulting activity is generally not as intense due to weaker features due to lack of upper-level support
  - » Along with low-level heating, this is the frequent cause of air mass thunderstorm activity that dominates the southeast US in the summer

Convective Air masses and Synoptic Patterns

- Sea breeze / lake breeze fronts intersecting other boundaries
  - » Basically the same as outflow boundary intersections
  - » Sea / lake breeze fronts often converge upon each other due to the slope of the coastline (points, peninsulas)
  - » Intense convection frequently results and often creates a climatological maximum for thunderstorm activity

WSR-88D Severe Weather Products

- Base Reflectivity
  - Many characteristic weather features can be identified using Base Reflectivity
    - Hook echoes
      - Classical signature associated with tornadic activity
      - The hook is not the tornado itself but rather the precipitation wrapped around the rotating vortex
      - Hook is often obscured by surrounding precipitation

WSR-88D Severe Weather Products

- Look for hooks at lowest elevation angle (not a hard and fast rule)
- The mesocyclone and tornadic vortex signatures on velocity products are more reliable for tornado detection
- Evidence on more than one product is desirable

WSR-88D Severe Weather Products

- Strong low-level reflectivity gradients
  - Finer resolution makes these gradients more detectable than before
  - Color vs Iso-Echo feature of FPS-77 makes gradients more visible
  - Mid-level storm overhang can be related to this low-level gradient for evaluation of storm severity
  - In general, strong low-level reflectivity gradients should alert you to possible storm severity and further analysis is recommended

WSR-88D Severe Weather Products

- Line Echo Wave Patterns (LEWP's)
  - Line of thunderstorms which has been subjected to an acceleration along one portion
  - Easily distinguishable on WSR-88D reflectivity products
  - Severe weather is normally expected at, and slightly south of the wave crest or bow echo

WSR-88D Severe Weather Products

- Embedded Thunderstorms
  - Embedded convection is easily identifiable with color products
  - 10 7 cm wavelength is less attenuated by precipitation
- Outflow Boundaries
  - Horizontal airflow resulting from cooler, denser air sinking and spreading out at the ground
  - Can be seen on WSR-88D even if no clouds are present because of the gradient in the refractive index

WSR-88D Severe Weather Products

- Melting Level
  - That level where descending frozen precipitation particles begin melting
  - As melting begins, droplets coalesce and cause an area of enhanced reflectivity
  - Appears as a ring or partial ring of enhanced reflectivity around the RDA
  - Usually detectable in stratiform weather conditions

WSR-88D Severe Weather Products

- Tilt Sequence Method of Severe Storm Detection
  - It was developed by Leslie R Lemon using WSR-57 data as an objective method to identify storms containing the horizontal and vertical characteristics indicative of severe weather production
  - To conveniently compare echo distributions at various heights, employ quarter screen mode
    - » Quad 1 - 0 5˚ elevation is examined to determine storm inflow (characterized by low-level concavity bounded by a strong reflectivity gradient with echo core displaced toward that flank)
    - » Quad 2 and 3 - identify maximum mid-level overhang (occurs from 5 to 12 km, 16-25 kft), may be necessary to examine 2 or 3 intermediate elevation angles to identify

WSR-88D Severe Weather Products

  - » Quad 4 - identify storm maximum top (Echo Tops Product, or if finer resolution is needed, the highest elevation angle of detection)

- Echoes having or developing intense updraft (strong severe weather potential) normally display the following characteristics on the updraft flank (generally the right rear, but occasionally the rear or left rear)
- Strong or intense low-level reflectivity gradient with echo core displaced toward that flank
- Low-level concavity bounded by strong reflectivity gradients

WSR-88D Severe Weather Products

- 6 to 25 km (3 2 to 13 5 nm) of mid-level overhang beyond the low-level echo edge, capped above by a major reflectivity core (> 46 dBZ), further capped by the maximum echo top (found over the strong gradient)
- Beneath the overhang is the WER
- Once a storm reaches the mature stage the BWER may develop
- It appears as a circular region of low reflectivity extending upward within the mid-level overhang typically < 8 km (4 3 nm) in diameter

WSR-88D Severe Weather Products

- Located near the center of, or toward the south flank of the overhang, bounded by an intense gradient, capped by echo core (> 46 dBZ), and the echo top
- If a storm exhibits these characteristics severe weather production potential is high
- Verification of severe weather occurrence is 71%

WSR-88D Severe Weather Products

- Other Echo Characteristics
  - In some short-lived severe storms (10-25 minutes) the only indication of severity may be a core > 50 dBZ extending at least 27,000 ft vertically
  - On the downstream flank (relative to mid- and high-level winds) the low-level echo may exhibit two lobes caused by deflection of flow on either side of an intense blocking updraft
  - A well-defined pendant accompanied by extensive mid-level overhang is a good indication of impending tornado development
  - Further indication of tornado development occurs if the pendant wraps up into a hook echo
  - If the wrap up is accompanied by a collapse of the WER and echo top, potential for tornado production is extreme

WSR-88D Severe Weather Products

- Criteria for Severe Thunderstorm using the Tilt Sequence Method follow
  - > 50 dBZ extends to 27,000 ft AGL or higher in absence of this, all the following must be satisfied
  - Peak mid-level (16,000 to 39,000 ft AGL) reflectivities must be > 46 dBZ
  - Mid-level overhang must extend at least 6 km beyond the strongest reflectivity gradient of the low-level echo
  - Max echo top must be located on the storm flank possessing the overhang and above the low-level gradient between the echo core and echo edge, or lie above the overhang itself

WSR-88D Severe Weather Products

- Criteria for tornado identification using the Tilt Sequence Method requires the last three criteria above be met and either or both of the following
  - A low-level pendant exists beneath or bounds the mid-level overhang on the west
  - A BWER is detected

WSR-88D Severe Weather Products

- Some weather features may be seen in both clear air and precipitation mode
- Detection depends on the following
  - Moisture availability with the particular event
  - Refractive atmospheric conditions during these events

WSR-88D Severe Weather Products

- Cutoff for precip vs non-precip is generally about 18 dBZ
  - Precipitation mode looks down to approximately 5 dBZ
  - You'll see many events never before seen on FPS-77 or WSR-57 type radars

WSR-88D Severe Weather Products

- Base Velocity
  - Base velocity is the average velocity of the air flow parallel to the radar beam within the sample volume
  - Although a single Doppler radar measures only the radial component of the wind, a wide variety of weather features can be easily identified

WSR-88D Severe Weather Products

- Vertical Variations - full screen presentation
  - Represents the wind from the surface to some height above the ground
  - As the radar beam moves away from the antenna, the height of the radar beam increases
  - Full screen represents a conically shaped pseudo 3-D display

WSR-88D Severe Weather Products

- Determining Wind Direction
  - Recall that a single Doppler radar measures only the radial component of the wind
  - To determine wind direction you must know beam orientation
  - The Doppler zero line is extremely important in determining wind direction
    - As the radar beam encounters winds that are perpendicular to the beam--zero velocity is detected
    - Since zero velocity is detected each time the beam encounters a perpendicular wind, a distinct line of zero velocities emerges during a 360˚ sweep

WSR-88D Severe Weather Products

- Determining wind direction for a specific height
  - Select a point along the zero velocity line
  - Draw a radial line from the antenna location bisecting the point
  - Draw a line through the point so as to bisect the radial perpendicularly
  - Determine overall flow
  - Wind direction is the same as the orientation of the perpendicular line

WSR-88D Severe Weather Products

- Determining Wind Speed
  - Determine wind direction
  - From the point on the zero line move 90˚ toward the direction the wind is from
    - » You must remain the same distance from the radar when you move 90˚
    - » You move 90˚ to get to where the radar is sensing the full component of the wind
  - Read speed here by comparing the color to the value on the color bar

WSR-88D Severe Weather Products

- Examples of vertical wind profiles
  - Direction
    - » Constant (top row of slide)
      - a. Zero line oriented straight across the display
      - b. Zero line orientation dictates wind direction
    - » Uniform change in direction (middle row)
      - a. S-shaped zero line
      - b. Zero line orientation indicates wind direction

WSR-88D Severe Weather Products

» Non-uniform change in wind direction (bottom row)

1. Constant speed throughout display (1st column)

a. All velocity contours pass through the center of the display

b. Speed is the same for all heights

WSR-88D Severe Weather Products

2. Steadily increasing speed with height (2nd column)

a. Contours steadily change from the center out to the edge of the display

b. All contours less than or equal to the surface wind pass through the center of the display

WSR-88D Severe Weather Products

3. Speed profile containing a speed maxima (jet) (3rd and 4th columns)

a. Contains a pair of peak velocities

b. Velocity peaks appear as closed contours ~ 180° from each other

WSR-88D Severe Weather Products

- Veering winds
  - » Representative of warm-air advection
  - » Produces a forward S-shaped zero line
- Backing winds
  - » Representative of cold-air advection
  - » Produces a backward S-shaped zero line

WSR-88D Severe Weather Products

- Low and mid-level jets
  - » Whenever there is a speed max or jet within the display, there is a pair of closed contours 180˚ (directly opposit) from each other
  - » The WSR-88D can calculate the height for you upon request
- Turbulence
  - » Abrupt changes in wind speed and/or direction
  - » Depth and height is obtained using antenna elevation and slant range to that point

WSR-88D Severe Weather Products

- Frontal boundaries
  - » Usually marked by a strong shift in velocity values
  - » Sharp bends in the zero line and close packing of velocity contours indicates the presence of a frontal zone
  - » Excellent for tracking frontal boundaries as they transition through the radar coverage area
- Overrunning
  - » Large scale precipitation events signify that the dynamics are present
  - » This is readily seen using the WSR-88D’s Velocity display

WSR-88D Severe Weather Products

- Horizontal Variations - individual storm signatures
  - Horizontal variations mean small signatures within individual storms
    - Rotation
      - » Found within mesocyclones and tornado bearing storms
      - » Make-up (when signature is located to the north of the radar)

        a. Zero line is parallel to the radar beam

        b. Velocity at the center is zero and increases linearly to a maximum value at the core

        c. Velocity decreases linearly from the maximum out to the edge of the signature

WSR-88D Severe Weather Products

- Divergence
  - » Found near the storm top above the updraft and near the ground in the precipitation downdraft
  - » Make-up (when signature is located to the north of the radar)

    a. Zero line is perpendicular to the radar beam

    b. Inbound velocities are located on the radar side of the signature

    c. Outbound velocities are located opposite the inbound velocities

WSR-88D Severe Weather Products

- Convergence
  - » Found near the surface below the storms updraft
  - » Make-up (when signature is located to the north of the radar)

    a. Zero line is perpendicular to the radar beam

    b. Outbound velocities are located on the radar side of the signature

    c. Inbound velocities are located opposite the outbound velocities

WSR-88D Severe Weather Products

- Real examples (the following example shows the 3 signatures discussed in one storm)
  - Quadrant 1
    - » elevation showing low-levels of storm
    - » Convergence
  - Quadrant 2
    - » elevation showing mid-levels of storm
    - » Rotation

WSR-88D Severe Weather Products

- Quadrant 3
  - » elevation showing upper-levels of storm
  - » Divergence

WSR-88D Severe Weather Products

- Applications/Interpretation
  - Precipitation mode, (Mode A) usage
    - Determine storm structure, flow characteristics, wind strengths
    - Identify TVS’s, mesocyclones, convergence, and divergence by changes in the wind profile
    - Determine the location and movement of troughs, fronts, and other boundaries
    - Climb winds
    - Identify suspected areas of turbulence
    - LLWS

WSR-88D Severe Weather Products

- Clear air or non-precipitation mode (Mode B) usage
  - Determine climb winds for aircraft briefings
  - Determine turbulent areas for local flight briefings
  - Determine location and motion of troughs, fronts, and other boundaries by changes in the wind profile
  - LLWS (Low Level Wind Shear)

WSR-88D Severe Weather Products

- Spectrum Width is a measure of the velocity differences or spread within the sample volume
  - The Spectrum width product can be used to estimate turbulence associated with the following
    - Fronts
    - Gust fronts or outflow boundaries
    - Shear zones
    - Identification of convection embedded in stratiform precipitation (especially in snow events)

WSR-88D Severe Weather Products

- Verification studies for spectrum width values vs turbulence severity are not conclusive Guidelines include
  - Values of 12 knots or higher have been correlated with severe turbulence
  - Values of 8 - 11 knots have been associated with moderate turbulence

WSR-88D Severe Weather Products

- The Spectrum width product is not specifically designed to assist forecasting icing
  - The spectrum width product can be used to help indicate areas of icing based upon variable fall velocities, i.e. rain and snow mixed
  - Melting level may appear as a ring or partial ring around the radar

WSR-88D Severe Weather Products

- Spectrum width can be used to detect early stages of convection
  - Convective currents may cause localized areas of higher spectrum width
  - Often detectable before visible cloud droplets form

WSR-88D Severe Weather Products

- The primary use of the Spectrum Width product is to indicate the reliability of base data
  - Width values are high in areas of poor signal-to-noise data (noisy)
  - Velocity estimates are generally considered more reliable in areas of low spectrum width

WSR-88D Severe Weather Products

- Composite Reflectivity (CR) provides a synopsis of the most highly reflective features within the 124 or 248 nm coverage area and up to 100 storms are tracked
  - Correlation
    - Can be first step in identifying significant weather features
    - Should be used with other products, should not be used by itself

WSR-88D Severe Weather Products

- Quick Check
  - Good for quick identification of stronger storms
  - Reduces the possibility of missing a strong storm due to choice of elevation slices in the RPS list

WSR-88D Severe Weather Products

- Melting Level
  - In the past the melting level could only be identified as a bright band
  - On the CR product it shows up as a ring or a partial ring and the height is easily determinable

WSR-88D Severe Weather Products

- Layered Composite Reflectivity Maximum (LRM)
  - Convective Regimes
    - Useful in determining the intensity trends/life cycle for severe storms
    - Mid and high layers are useful in identifying pulse convection

WSR-88D Severe Weather Products

- Correlation of Reflectivity Maximum with Height
  - Height range of maximum reflectivities is easily identified
  - Mid layer is helpful in determining heavy precipitation in tropical regimes
  - Mid layer can help differentiate precipitable echoes from non-precipitable echoes

WSR-88D Severe Weather Products

- Vertically Integrated Liquid (VIL)
  - Use of the VIL
    - Intended to provide user with an indication of convective storm severity
    - Allows operator to quickly locate most significant storms
    - Can be an effective tool for determining hail producing storms when site specific WSR-88D critical thresholds have been established

WSR-88D Severe Weather Products

- Significant values
  - Must be determined for each region of operation
  - Values considered high for one area of the country may not be considered significant in another
  - Examples:
  - Severe storms in New England only produced values of approximately 45 kg/m^2
  - Severe storms in Oklahoma produced VIL values of at least 55 and some were over 70
  - Seasonal and airmass variations must also be considered

WSR-88D Severe Weather Products

- Rapid changes in VIL values
  - Rapid increases to high values often signal a transformation to a severe storm structure (may indicate a non-severe multi-cell changing to a severe supercell)
  - Rapid declines from high values may signal a storm collapse
  - These collapsing storms are often the cause of severe downburst winds

WSR-88D Severe Weather Products

- May be useful even during stratiform regimes to locate areas of heavy rainfall or embedded convective activity
- Helps delineate thunderstorms from rainshowers, often better than Base Reflectivity

WSR-88D Severe Weather Products

- Severe Weather Probability (SWP)
  - Severe weather likelihood
  - Helps objectively determine the likelihood of a given convective storm producing large hail, damaging wind, or tornadoes

WSR-88D Severe Weather Products

- Values are relative and for a given weather event, those storms with the highest SWP are more likely to produce severe weather
  - Do not interpret as actual probability of severe weather and values are relative to each other only
  - Do not relate a SWP of 75% on one day, under specific weather conditions, to a 75% another day
  - Changing weather regimes which affect the VIL's performance also affect the SWP's performance

WSR-88D Severe Weather Products

- Developed solely to evaluate extratropical convective storms
- As with VIL, SWP is most reliable as a hail assessment product
- Shown to be less reliable for other severe weather phenomena

WSR-88D Severe Weather Products

- Often overlaid on the VIL
  - Allows the operator to see VIL values from which SWP's are derived
  - Use care not to mistake the SWP numbers as VIL values
  - VIL's are color pixels to match with the data levels in the legend
  - SWP's are simply numbers
- Relatively low VIL's with high SWP's indicate fast moving, or strongly tilted storms

WSR-88D Severe Weather Products

- Echo Tops (ET)
  - Application/Interpretation
    - Provides an indication of the upper boundary of significant (18 5 dBZ) reflectivity
    - Echo tops for rapidly growing convective echoes are close approximations of the visual cloud tops of these echoes
    - Primarily used as a first estimate of the most intense convection and for aviation briefing purposes
    - Detection of collapsing echo tops may aid in timing the onset of downbursts, microbursts, and tornadoes

WSR-88D Severe Weather Products

- Storm Total Precipitation (STP) and User Selectable Precipitation (USP)
  - STP
    - Monitoring of total precipitation accumulation regardless of duration
    - Post storm analysis
    - NWS uses
    - Estimation of total basin run-off due to a single storm
    - Estimation of basin saturation due to previous rainfall
    - Evaluation of flood reports

WSR-88D Severe Weather Products

- USP
  - Monitoring of precipitation accumulation for a user specified time period
  - Post storm analysis
  - NWS uses
  - Estimation of total basin run-off due to a single storm
  - Estimation of basin saturation due to previous rainfall
  - Evaluation of flood reports

WSR-88D Severe Weather Products

- Storm Relative Mean Radial Map (SRM) and Storm Relative Mean Radial Region (SRR)
  - Applications/Interpretation
    - Primary use is to locate an area of rotation when a classic rotational couplet does not exist
      - SRR
        - » Comparison
          - a. Base Velocity
          - b. Storm Relative Mean Radial Region

WSR-88D Severe Weather Products

- SRM
  - » Comparison
    - a. Base Velocity
    - b. Storm Relative Mean Radial Velocity Map

- Primary use is as an aid in identifying mesocyclones and other storm relative vortical flows
- Window (SRR) product can be requested as part of the Severe Weather Analysis when interested only in a single storm
- Using a storm motion of zero yields the display of maximum measured RDA relative velocities

WSR-88D Severe Weather Products

- User can allow the product to default to the storm track output or supply a direction and speed of their own
- For a line of thunderstorms or a convective system where storm motions are similar, an average storm motion (computer or user input) can be removed

WSR-88D Severe Weather Products

- Velocity Azimuth Display (VAD)/VAD Winds Profile (VWP)
  - VAD
    - Applications/Interpretation
      - Quality control for the VWP product
      - Provides an accurate wind measurement for a specific altitude

WSR-88D Severe Weather Products

- Identifies areas of convergence and divergence
  - If the outbound (positive) portion of the sinusoidal wave has greater amplitude than the inbound (negative), then speed divergence exists
  - If the inbound (negative) portion of sinusoidal wave has greater amplitude than the outbound (positive), then speed convergence exists
  - If the inbound (negative) portion of sinusoidal wave is wider than the outbound (positive) portion then directional convergence (confluence) exists
  - If outbound (positive) portion of sinusoidal wave below is wider than the inbound (negative) portion, then directional divergence (difluence) exists

WSR-88D Severe Weather Products

- VWP
  - Application/Interpretation
    - Available in both clear-air and precipitation modes
    - Representative of the environmental flow
    - Usage
      - » Aviation briefings
        a. Climb winds
        b. Turbulent areas
      - » Forecasting

WSR-88D Severe Weather Products

- Backing and veering winds
- Monitor the development/evolution of jets
- Can infer temperature advection
- Frontal slope
- Drying - loss of data may indicate drying
- Location of inversion

WSR-88D Severe Weather Products

- Mesocyclone
  - Application/Interpretation
    - Vortical flow fields
    - Tailored to identify the vortical flow field associated with the updraft of a severe convective storm
    - At times it identifies microbursts associated with vortical flow

WSR-88D Severe Weather Products

- Mesocyclone detection and storm relative velocity products
  - Step 1
    - Determine if sufficient rotational velocity exists between closed isodops of opposite sign
    - Compute the rotational velocity
      - » Subtract max outbound minus max inbound
      - » Divide this number by 2

WSR-88D Severe Weather Products

- Significant shear is defined as rotational velocity of
  - » knots within 80 nm
  - » knots between 80 and 125 nm
- The azimuthal diameter between the maximum inbound and maximum outbound velocity must be less than 5 nm

WSR-88D Severe Weather Products

- Step 2
  - Determine vertical continuity
  - Vertical extent can be as small as 50% of the horizontal diameter but never less than 10 kft
  - Even with VCP 11, 1 5° may be too high to detect distant mesocyclones
  - Therefore recognition may have to be achieved without satisfying a vertical continuity check

WSR-88D Severe Weather Products

- Step 3
  - Shear pattern should persist for at least 2 volume scans
  - Remember, mesocyclone products do not establish time continuity

WSR-88D Severe Weather Products

- Mesocyclone vs weather events
  - Less than 1/2 of all verified mesocyclones produce tornadoes
  - Of all verified mesocyclones produce some form of severe weather
  - Some storms produce a series(families) of mesocyclones and tornadoes
  - Primary use of this product is to alert the user to the possible existence of a severe weather producing storm

- Tornadic Vortex Signature (TVS) - FMH-11, part C, pg 2-88
  - Applications/Interpretation
    - Used to identify the high shear signature sometimes associated with strong to violent tornadoes at relatively close range (μ 50nm)
    - Primary use is to alert the user to the possible existence of a tornado bearing storm

WSR-88D Severe Weather Products

- TVS detection and storm relative velocity products
  - Step 1
    - Significant localized shear must exist between azimuthally adjacent sample volumes
    - Localized shear is defined as
    - At least 90 knots at ranges less than 30 nm
    - At least 70 knots at ranges greater than or equal to 30 nm
    - TVS detection beyond 55 nm is difficult due to beam limitations and size of the TVS

WSR-88D Severe Weather Products

- Step 2 - the localized shear should extend several thousand feet in the vertical, at least 2 elevation angles, not necessarily contiguous
- Step 3 - the localized shear should have time continuity This should be present for the period of two volume scans

WSR-88D Severe Weather Products

- Severe Weather Analysis Products (SWA)
  - Primarily intended for the detailed analysis of potentially severe weather and are window products
  - Allows the user to view all three radar moments simultaneously in the highest resolution available

WSR-88D Severe Weather Products

- Reflectivity (SWR)- allows identification of severe weather reflectivity signatures such as
  - Hook Echoes are associated with tornadic activity
  - Strong Reflectivity Gradients when associated with mid-level overhang may be indicative of a severe storm
  - Line Echo Wave Patterns has the highest potential for severe weather and tornadic activity is at and slightly south of the crest

WSR-88D Severe Weather Products

- Outflow Boundaries can cause strong surface winds many miles from the parent storm
- Time permitting, reflectivity signatures should be correlated with Velocity and Spectrum Width features to verify the existence of potential severe weather

WSR-88D Severe Weather Products

- Velocity (SWV)- used to identify severe weather velocity features and their correlation to reflectivity signatures
  - Tornadic Vortex Signature
    - Strong rotational couplet often found within a preexisting mesocyclone
    - When correlated with a hook echo on the Reflectivity panel, tornadic activity is occurring or eminent

WSR-88D Severe Weather Products

- Low-Level Convergence
  - It is found beneath the storm's updraft
  - When correlated to a strong reflectivity gradient it is indicative of an intense updraft
  - Strong potential for severe weather is present
- Outflow Boundaries
  - It is much like frontal boundaries, are denoted by a significant change in the zero line
  - This change in orientation should correlate with an outflow boundary on the Reflectivity Product

WSR-88D Severe Weather Products

- Line Echo Wave Patterns correlates with a mesocyclone or tornadic vortex signature with the reflectivity LEWP is strong evidence of severe weather

WSR-88D Severe Weather Products

- Spectrum Width (SWW) is used to determine the existence of strong shear in storms too far from the RDA to identify velocity couplets, and confirm the shear zones associated with couplets found in the Velocity pattern
  - High Spectrum Width values should correlate with the velocity and reflectivity features just discussed
  - Exception, storms near the RDA may not display high values due to the extremely small sample volumes

WSR-88D Severe Weather Products

- Small scale features, such as rotation, convergence, and divergence may not be visible in the velocity pattern at long distances
- High spectrum width values may be the only indication these features exist

WSR-88D Severe Weather Products

- Radial Shear (SWS) is the velocity differences (shear) between three radially adjacent sample volumes
  - Primarily intended to detect the existence of microbursts/downbursts
  - The algorithm is still being fine tuned and no data exist correlating radial shear to microbursts or downbursts
  - Useful in bringing the operators eyes to areas of potential divergence/convergence
  - Requires verification on velocity products

WSR-88D Severe Weather Products

- Maximum Data Levels are located within the displayed window
  - Operators can quickly identify and locate the maximum reflectivity value of a specific storm
  - Very useful in determining rotational velocities or tangential shear of velocity couplets
  - Since Velocity and Spectrum Width display every sample volume, the maximum data level is easily located

WSR-88D Severe Weather Products

- Storm Relative Velocity Region (SRR) - can be substituted for the Radial Shear Panel
  - Usually more useful than radial shear
  - Interpretation of SRR was discussed in the velocity derived products section

Cross Section Products (RCS, VCS, SCS)

- Vertical viewing of storms or other radar features along a selected path of interest
- Reflectivity Cross Section
  - Numerous meteorological features may be analyzed
  - It is important to remember these features should be correlated with features in other products (such as the Velocity and/or Spectrum Width Cross Section) before arriving at final conclusions as to their meteorological significance

Cross Section Products (RCS, VCS, SCS)

- Clear-air Mode
  - Depth of the Moist Layer can be determined by measuring the vertical extent of scatterers
  - A Cross Section cut perpendicularly through a dry frontal boundary allows the operator to determine frontal slope and to extrapolate the surface frontal position

Cross Section Products (RCS, VCS, SCS)

- Features which are denoted by a change in refractive index (Freezing Level, Inversions, etc) may be analyzed
  - Appear as a band of enhanced reflectivities suspended above the earth's surface (bright band)
  - Can monitor their development/evolution, and increase/decrease in altitude

Cross Section Products (RCS, VCS, SCS)

- The height of cloud bases and or tops can be determined
  - When looking down to -28 dBZ even ice crystals in cirrus can be detected
  - Objective means for assigning heights to cloud layers in the observation
  - Can monitor cloud layer development, thickening, thinning, etc

Cross Section Products (RCS, VCS, SCS)

- Precipitation Mode
  - Analysis of convective storm severity is largely based on the strength of the storm's updraft

Cross Section Products (RCS, VCS, SCS)

- The most common vertical reflectivity feature used in determining whether an updraft is strong enough to support severe weather is the Weak Echo Region, or in the late mature stage, the Bounded Weak Echo Region (vault)
  - Appears as an area of significantly lower reflectivities extending vertically through a storm
  - Usually found below the maximum top, and above the storm inflow
  - As the storm matures and the updraft intensifies the Weak Echo Region often becomes bounded on either side by higher reflectivity values
  - This indicates strong potential for severe weather

Cross Section Products (RCS, VCS, SCS)

- The height of the maximum reflectivity core is another good indicator of the intensity of storm updraft
  - Found above the product area in alphanumeric format
  - Reflectivity cores above 50 dBZ in the mid or upper mid levels of a storm are indicative of an intense updraft
  - An extremely intense updraft is necessary to hold that much mass aloft

Cross Section Products (RCS, VCS, SCS)

- Side lobes can cause a feature known as a Hail Spike to occur
  - Appears as a narrow finger of reflectivity extending from the top of a storm
  - It is not the actual top, but rather misplaced data collected from a side lobe
  - Caused by a lobe of energy (side lobe) not from the main beam encountering a target while the antenna is angled upward
  - The radar places the data at the range and elevation angle it would have been if it had been collected from the main beam

Cross Section Products (RCS, VCS, SCS)

- Another outstanding method used to interrogate the vertical structure of a storm is to cut a Reflectivity Cross Section so that it bisects the low-level reflectivity gradient and extends outward to the right rear quadrant with respect to storm motion Then analyze for
  - At least 6km of overhang in the mid-levels of the storm
  - Max top of the storm over the low level gradient
  - The existence or development of a Weak Echo Region or Bounded Weak Echo Region

Cross Section Products (RCS, VCS, SCS)

- Velocity Cross Sections is used when interrogating potentially severe storms, analysis of the vertical velocity structure is essential
  - The operator must be aware of the orientation of the cross section plane to the RDA to correctly interpret the product
    - Must be cut either parallel or perpendicular to a radial
    - If cut at any other angle, the data are radial components of radial velocities and extremely time consuming if not impossible to interpret

Cross Section Products (RCS, VCS, SCS)

- The product always presents the data from westernmost to easternmost points, or northernmost to southernmost points (when the plane is north - south oriented)
- Convergence north of the RDA appears identical to divergence south of the RDA
- Cyclonic rotation north of the RDA appears identical to anticyclonic rotation south of the RDA
- Likewise, same features are mirror images at any direction when located on opposing sides of the RDA

Cross Section Products (RCS, VCS, SCS)

- Clear-Air Mode
  - Turbulent layers may be analyzed
    - » Existence and or intensity of a turbulent layer is estimated by computing the vertical shear per 1000 ft
    - » Use shear values from AWSP 105-56
  - Boundary Layer - appears as either the top of the scattering region, or the level where significant wind change occurs
  - Frontal slope is often easier to determine on the Velocity Cross Section
    - » Appears as a significant change in wind direction and speed
    - » Calculated in the same manner as in Reflectivity

Cross Section Products (RCS, VCS, SCS)

- Precipitation Mode
  - All applications in clear-air mode also apply to precipitation mode
  - Velocity Cross Sections provide an excellent way to classify vortical flow fields
    - » The operator **MUST** be aware of the Cross Section's orientation to the RDA to avoid misinterpretation
    - » Allows the operator to determine if mesocyclone rotational velocity criteria are met, and establish vertical correlation on one product

Cross Section Products (RCS, VCS, SCS)

- The same is true for Tornadic Vortex Signature (TVS)
- If these features correlate with a hook echo, or flow around an obstacle signature in the Base Reflectivity product, a strong case for severe weather exists
- To see rotation the cross section must be cut essentially perpendicular to a radial

Cross Section Products (RCS, VCS, SCS)

- Convergence can be analyzed by cutting a Velocity Cross Section parallel to a radial
  - » Often identifies frontal zones or outflow boundary
  - » A strong convergent signature below a storm updraft indicates an intense updraft exists
  - » Potential for severe weather is high especially if correlated with a strong reflectivity gradient on the Base Reflectivity product

Cross Section Products (RCS, VCS, SCS)

- Divergence can also be analyzed by cutting a Velocity Cross Section down a radial
  - » The magnitude of divergence at the storm summit directly correlates to the potential hail size a storm will support
  - » Divergence at the base of a storm is indicative of a downburst/storm collapse
  - » Can cause strong surface winds miles from the parent storm
  - » Largest hail is likely during the collapse

Cross Section Products (RCS, VCS, SCS)

- Spectrum Width Cross Section
  - Clear-air Mode
    - High Spectrum width values indicate potential turbulence
    - The freezing level and inversions appear as layers of relatively higher values
  - Used to verify data from a Velocity Cross Section

Cross Section Products (RCS, VCS, SCS)

- Precipitation Mode - localized high values may indicate the existence of a vortical flow field
  - Correlate with Velocity to verify the existence of Meso, or TVS
  - Due to beam broadening high Spectrum Width values may be the only indication that a Meso or TVS exists in storms located at long ranges from the RDA
  - In predominantly stratiform layers the freezing level is often indicated by a layer of high Spectrum Width values

Cross Section Products (RCS, VCS, SCS)

- Orientation to the RDA
  - Velocity Cross Sections **MUST** be cut either parallel or perpendicular to a radial to be useful
  - Velocity Cross Sections parallel to a radial allow determination of convergent or divergent flow
  - Perpendicular cuts allow determination of rotational flow fields
  - The location with respect to the RDA must also be known to classify flow fields

Cross Section Products (RCS, VCS, SCS)

- Convergence one direction from the RDA looks the same as divergence on the opposing side
- Cyclonic rotation on a given side to the RDA appears the same as anticyclonic rotation on the opposing side

Cross Section Products (RCS, VCS, SCS)

- Interpolation
  - Data gaps in the volume coverage pattern cause course resolution due to the interpolation strategy employed
  - Will not extrapolate above the highest elevation angle or below the lowest elevation angle

Cross Section Products (RCS, VCS, SCS)

- Storm Cell Identification and Tracking - provides information on a storm cell's present, past, and future positions (FMH-11, part C, pg 3-18)
  - Comprised of the following algorithm
    - storm cell segment
    - storm centroids
    - storm tracking
    - storm position

Cross Section Products (RCS, VCS, SCS)

- Storm Tracking Information Product
  - The Graphic Product - displays (up to 100) storm's past, present, and future positions
  - Past Position - represented by a solid dot plotted at all previously known storm positions (up to 13 volume scans back)
  - Present Position - represented by a circled X indicating the current storm position

Cross Section Products (RCS, VCS, SCS)

- Future Position - represented by an X indicating the projected storm positions at user defined time intervals (default value is 15 minutes)
  - A "forecast error" is computed by comparing a storm's location to its projected position based on its previous location and speed
  - The number of forecast positions is dependent on the accuracy of the past forecast positions
- Past, present and future positions of each storm are connected by a solid line
- Cells with movement of less than a minimum speed(default=5knots) are circled to indicate little movement

Cross Section Products (RCS, VCS, SCS)

- The product includes an attribute table consisting of the following
  - Storm ID
  - Storm location
  - Forecast movement
  - Tracking error
  - Maximum dBZ and its height for each storm
- STI is most effective when overlaid on a geographically-based product

Cross Section Products (RCS, VCS, SCS)

- The Alphanumeric Product
  - STI is displayed in alphanumeric format via the applications terminal
  - The product display includes
    - Storm ID number
    - Current AZRAN position
    - The direction and speed from which the storm is moving

Cross Section Products (RCS, VCS, SCS)

- AZRAN of 15, 30, 45, and 60 minute forecast positions
- Forecast track error
  - » FCST - tracking error from latest volume scan
  - » MEAN - average tracking error over life span of storm

Cross Section Products (RCS, VCS, SCS)

- Hail Product - computes the probability of hail for storm cells within 124 nm of the RDA
  - The graphic product displays several hail identification symbols
  - A small, open or solid green triangle denotes probability of any size hail (POH)
  - A large, open or solid green triangle denotes probability of severe hail (POSH)

Cross Section Products (RCS, VCS, SCS)

- Maximum Detected Hail Size (MEHS) will be displayed in the center of the POSH symbol
  - Rounded to the nearest inch (1 to 4)
  - An asterisk (*) denotes hail size less than 3/4 inch
- Whether the triangle is open or solid depends on a "fill-in" threshold set by the operator for a specific percentage of occurrence
- A green attribute table, which lists storm ID, AZRAN, POH/POSH, MEHS, and 0˚/-20˚C altitude, is also available upon user selection

Cross Section Products (RCS, VCS, SCS)

- The hail product is most effective when overlaid on geographically-based products
- It can, however, be used as a stand-alone product

Cross Section Products (RCS, VCS, SCS)

- Alphanumeric Hail Product
  - The hail product is available as an alphanumeric product via the applications terminal
  - The product display includes
    - Storm ID
    - POH
    - POSH
    - MEHS (rounded to the nearest 1/4 inch, < 50 to>4 00)

Cross Section Products (RCS, VCS, SCS)

- Storm Structure
  - The Storm Structure product displays the storm characteristics calculated by the SCIT algorithm
    - This product must be in the PUP database for Cell Trends to be displayed, and is therefore recommended for the RPS list

Cross Section Products (RCS, VCS, SCS)

- Information includes
  - Storm ID
  - Centroid AZRAN
  - Storm base/top (Kft)
  - Cell-based VIL
  - Maximum reflectivity in the cell
  - Height of the maximum reflectivity
- Adaptable parameter - storm structure does not have any However, all other series adaptable parameters affect storm structure

Cross Section Products (RCS, VCS, SCS)

- Cell Trends is a graphic display providing the user with up to a 10 volume scan history of cell parameters for algorithm-identified storm cells
  - The Storm Structure product is the sole input for this graphic
  - Cell Trends is not a product, it has no product ID# or mnemonic, nor can it be archived (may be generated from archived Storm Structure product)
    - Cell Trends is a display, much like NEXRAD UNIT STATUS
    - Cell Trends can only be generated from the graphics tablet

Cross Section Products (RCS, VCS, SCS)

- Presentation Format
  - Upper Left: Storm Top/Base (ARL), Height of Centroid, and Height of Maximum dBZ
  - Upper Right: Probability of Hail(POH), Probability of Severe Hail(POSH)
  - Lower Left: Cell-based VIL
  - Lower Right: Maximum Reflectivity
  - Product legend: Storm ID#, AZRAN, Graphical plot of cell location, and volume scan times included in trend data

Cross Section Products (RCS, VCS, SCS)

- Procedure
  - Select a storm of interest that has been identified by the Storm Cell Identification and Tracking (SCIT) algorithm (any geographically-based product can be used)
  - Toggle on the storm, using either the left or right puck button (selected point must be within 2 2nm of the storm centroid)
  - Toggle on the Cell Trends box in the Overlay area

Cross Section Products (RCS, VCS, SCS)

- Applications/Interpretations
  - Quick look at overall cell evolution
  - Status of Supercell/Microburst potential
  - Post-storm analysis

Severe Weather Tools

- Skew-T/Hodograph Analysis and Research Program (SHARP)
  - Description
    - SHARP is a NWS severe storm analysis and forecasting program
    - Used to plot and analyze Skew-T data
    - Hodographs
    - Several other severe thunderstorm forecasting techniques

Severe Weather Tools

- Allows for on-screen click and drag editing to forecast Skew-T data
- Instantly updates all parameters
- Computes additional data for six layers of the atmosphere

Severe Weather Tools

- Stability indices and forecast parameters
  - SHARP computes the standard stability indices
    - Examples:
      - » SWEAT Index
      - » Showalter Stability Index
      - » Lifted Index
      - » K-Index
      - » Total Totals

Severe Weather Tools

- System augments these analysis parameters with several new forecasting techniques These include
  - » Storm Relative Helicity
  - » Relationship between CAPE and Helicity
  - » Bulk-Richardson Number (BRN)
  - » Energy Helicity Index (EHI)

- Stability indices determine the magnitude of airmass stability
- Quantitative measurement techniques were devised to analyze the vertical distribution of temperature and moisture for convective potential

Severe Weather Tools

- Input
  - Uses standard RAOB data
  - Manual input is currently required using the SHED program

Severe Weather Tools

- Hodograph
  - Hodograph is a method of graphically displaying the winds
    - Winds are plotted as vectors relative to a single point with the speed shown in knots
    - Displays directional shear and pattern can indicate what type of thunderstorms are most likely to develop

Severe Weather Tools

- Hodograph with an unorganized structure are displayed as closely grouped, randomly distributed points
  - Wind speeds are normally very low
  - Commonly associated with single cell airmass type thunderstorms
  - Downdraft will fall back into the updraft, resulting in weakening and eventually death of the storm
  - Severe weather is rare with this type of configuration
  - Thunderstorms are relatively short-lived

Severe Weather Tools

- Hodographs with a straight-line structure have moderate directional shear with weak speed shear in the lower levels
  - Upper levels display strong speed shear with winds speeds rapidly increasing to > 60 knots
  - Configuration indicates the development of multicell structure storms
  - Can become severe especially when speed shear increases with height
  - This is typical of squall line or derecho type storms

Severe Weather Tools

- Hodograph with a curved structure indicates strong directional and speed shear in the lower 3 km of the sounding
  - Speed shear generally increases in the upper levels
  - Configuration is typical of supercell thunderstorm development and maintains a potential for strong to violent tornado development

Severe Weather Tools

- Storm motion winds are used to determine the mean storm inflow in the lowest 3 km relative to the storm motion
  - SHARP determines the mean wind flow by averaging the layers from surface to 6 km and is portrayed as a purple dot on the hodograph
  - Storm motion is then, initially, estimated as 75% of the mean wind, moving 30□ to the right of the mean wind
  - Using the storm motion winds, the mean storm inflow is computed

Severe Weather Tools

- Mean storm inflow is the movement of the low-level air relative to the storm motion
  - It is a must for storm development, with > 20 knots required for supercell development
  - It combines with strong directional shear to produce storm updraft rotation and tilt
  - It varies greatly with relatively small changes in the storm motion vector

Severe Weather Tools

- Stability Indices and Parameters
  - Showalter Stability Index (SSI)
    - A measurement of potential thunderstorm intensity
    - Requires that the low-level moisture layer ($D_{pD} \leq 6^{\circ}$ C) reaches 850-mb (LCL)
    - Compares the temperature of the parcel after being lifted to 500-mb to the environmental temperature at 500-mb

Severe Weather Tools

- This correlates to the buoyancy/updraft strength
- No provision for dynamic support or trigger mechanism
- Values equate to stability

> +3	Strong stability
> +1 to ≤ +3	Moderate stability
> -3 to ≤ +1	Weak stability/instability
> -6 to ≤ -3	Moderate instability
≤ -6	Strong instability (tornadic potential)

Severe Weather Tools

- Use
  - SSI determines the potential thunderstorm intensity based on the existing air mass
  - Not consider a trigger mechanism
  - Plotted Skew-T is needed to compute this index

Severe Weather Tools

- Procedure
  - Compute a LCL for the 850-mb level
  - At the LCL, lift the parcel, parallel to the moist adiabat, to the 500-mb level
  - Subtract this temperature from the observed 500-mb temperature
  - The difference is the SSI

Severe Weather Tools

- Lifted Index (LI)
  - Process is similar to the SSI, except for the depth of the low-level moisture layer
  - Uses the average low-level moisture layer within the lowest 3,000 ft (CCL) (100-mb)
  - It’s more useful than the SSI if the moist layer does not reach 850-mb

Severe Weather Tools

- Use the same values as SSI
  - Values of 0 to -2 are weak indication of severe thunderstorms, but showers are probable with some thunderstorms
  - Values of -3 to -5 indicates a moderate probability of severe thunderstorms
  - Values of < -6 indicates a strong probability of severe thunderstorms
  - All values > 0 indicate a stable atmosphere with NO thunderstorms likely

Severe Weather Tools

- Use
  - LI determines potential thunderstorm intensity based on the existing air mass
  - Not consider a trigger mechanism
  - Plotted Skew-T is needed to compute this index

Severe Weather Tools

- Procedures
  - Compute a LCL using the moist layer method (LCLml)
  - Consider the lowest 100 mb of the sounding as being the moist layer
  - to compute the LCLml, find the mean mixing ratio for the lowest 100 mb of the sounding using the equal area method
  - Next, find the forecast maximum surface temperature

Severe Weather Tools

- From this temperature, follow a dry adiabat upward until it intersects the mean mixing ratio
- This is the LCLml
- From the LCLml
  - » Lift the parcel upward, parallel to a moist adiabat, to the 500-mb level
  - » Subtract this lifted 500-mb temperature from the observed 500-mb temperature
  - » The difference is the LI

Severe Weather Tools

- Total Totals
  - Measures potential thunderstorm intensity
  - No trigger is considered
  - Compares the 850-mb temperature and dewpoint to the 500-mb temperature
    - It’s very sensitive to the 500-mb temperature
    - Works well for cold core activity

Severe Weather Tools

- Values are used to estimate severe thunderstorm potential
  - < 50 Weak
  - ≥ 50 to ≤ 55 Moderate
  - > 55 Strong

Severe Weather Tools

- Use
  - This index is also one of the easiest to compute
  - Skew-T is **NOT** required
  - You use a mathematical equation using the 850-mb temperature and dew point temperature, and the 500-mb temperature
  - The TT is actually a combination of two other indices They are the vertical total (VT) and the cross total (CT) TT = VT + CT

Severe Weather Tools

- Procedures
  - To compute TT, you need the 850-mb temperature (850T) and dew point temperature(850Td), and the 500-mb temperature (500T) As previously stated, the
  - TT = VT + CT
    - » VT = 850T - 500T
    - » CT = 850Td - 500T
  - TT = (850T + 850Td) - 2(500T)

Severe Weather Tools

- K-Index (KI)
  - Determines potential thunderstorm occurrence
    - No trigger considered
    - Does not measure the intensity
    - Can be translated into probability of thunderstorm occurrence

Severe Weather Tools

- Values that determines the chance of thunderstorm occurrence:

< 15	< 20%
15 to 20	20%
21 to 25	20-40%
26 to 30	40-60%
31 to 35	60-80%
36 to 40	80-90%
> 40	> 90%

Severe Weather Tools

- Use
  - Like the TT, the KI is relatively easy to compute
  - Skew-T is **NOT** required
  - Mathematical equation using the 850-mb temperature (850 T) and dew point temperature (850 Td), the 700-mb dew point depression (700 DpD), and the 500-mb temperature (500 T)

Severe Weather Tools

- Procedures
  - Find the 850T, 850Td, 700 DpD, and 500T
  - Use the equation: KI = (850T + 850Td) - (700 DpD) - (500T)

Severe Weather Tools

- Severe Weather Threat (SWEAT) Index
  - Measures potential thunderstorm intensity with no trigger considered
  - Only index to apply upper-level dynamics to static stability
  - Derived by computation only

Severe Weather Tools

- SWEAT = 12D + 20(T-49) + 2 f8 + f5 + 125(S + 2)
  - D = 850 mb dewpoint
  - T = total totals (TT)
  - f8 = 850-mb wind speed (ff)
  - f5 = 500-mb wind speed (ff)
  - S = sin(500-mb dd - 850-mb dd)

Severe Weather Tools

- Values or thresholds are fairly simple
  - indicates severe thunderstorms
  - indicates tornadoes

Severe Weather Tools

- Convective Available Potential Energy (CAPE)
  - Defined as the positive energy available for storm growth
    - It’s the area between the Level of Free Convection (LFC) and Equilibrium Level (EL) where the parcel of air is warmer than the surrounding environment
    - It’s referred to as buoyancy and denoted as B
    - CAPE can be either positive or negative
    - Positive CAPE (B+) indicates upward vertical motion (UVM) and a potentially unstable condition
    - Negative CAPE (B-) indicates downward motion with a stable condition

Severe Weather Tools

- Severe weather can occur with a wide range of CAPE values and is dependent on other factors
  - Values greater than 1,000 are associated with severe thunderstorms
  - Values >2,500 are commonly associated with tornadic development
  - Increases in CAPE values coincide with increases in both strength and speed of the updraft core
  - This maximum updraft speed is calculated by SHARP and displayed as MAX UVV (Upward Vertical Velocity)

Severe Weather Tools

- An increase in the strength of the updraft core corresponds to an increase in the likelihood of severe weather
- Larger the Positive Energy Area (PEA) on the Skew-T, the larger the CAPE will be

Severe Weather Tools

- Storm Relative Helicity
  - Represented by the shape of the hodograph curve
    - Can be positive or negative
    - Measures the amount of vertical shear in a storm's relative flow that's parallel to the mean wind
    - Storm relative helicity measures the potential for rotation in the thunderstorm's updraft

Severe Weather Tools

- Strong positive helicity is the parallel component that is flowing in the same direction as the mean wind
  - It sets up a cyclonic rotation in the storms
  - Usually associated with tornado bearing storms

Severe Weather Tools

- Strong negative helicity is the parallel component that is flowing opposite of the mean flow
  - It sets up anticyclonically rotating storms
  - Known as notorious hail producers
- Possible tornado strength can be determined as a function of helicity The stronger the helicity values
  - Greater the rotation of the updraft
  - Stronger the potential tornado strength

Severe Weather Tools

- CAPE vs Helicity
  - Two good severe weather indicators
    - Neither of these two can be used by themselves
    - Must be used together
    - Low CAPE may indicate no severe weather
    - But combined with a high helicity value
    - Can overcome to form intense rotating updrafts and strong tornadoes
    - If supported by strong inflow

Severe Weather Tools

- High CAPE values may also overcome low helicity values
- May still produce rapidly rotating updrafts and strong tornadoes

Severe Weather Tools

- Bulk Richardson Number (BRN)
  - National Weather Service developed this stability index based on relationship between CAPE and helicity
  - Used as an indicator of thunderstorm type in the high plains once other variables predict thunderstorm development
  - A low BRN value of < 10
    - Indicates that the updraft tilt will be too large to support deep convection
    - Results in storms shearing apart before the storms are capable of producing severe weather

Severe Weather Tools

- High BRN value of > 50
  - Indicates shear will be overpowered
  - Results in widespread convection with multi-cellular type storms
- Optimum BRN for severe convection is in the mid-ranges
- Moderate BRN values, between 15 and 35, provides the best balance for severe supercell thunderstorm development

Severe Weather Tools

- Energy Helicity Index (EHI)
  - Developed by the National Weather Service
  - Based on the relationship between CAPE and Helicity
  - Very useful as an indicator of tornadic activity and severity once other variables predict SEVERE thunderstorm development
  - Positive values indicate a potential for severe thunderstorm development and tornadoes

Severe Weather Tools

- Other Indices
  - Fawbush-Miller Index (FMI)
  - Martin Index (MI)
  - Thompson Index (TI)
  - Surface Potential Index (SPOT)

Severe Weather Tools

- Use of the Stability Indices
  - Best used as an analyzed field
  - Distribution of stability values shows areas of maximum instability
  - Use of a single station value can be seriously misleading due to changing air mass conditions between the time of the sounding (12Z), and the time of the activity (21Z)

Severe Weather Tools

- Best method is to examine individual parameters (temperature, moisture) affecting the stability index
- By examining conventional analyses (850, 500-mb charts)
  - Look for advection of favorable parameters
  - Stability indices are only a tool
  - There are many other considerations in the severe weather forecast

- APPLICATION: Interspersed throughout the lesson.
- EVALUATION: Appraisals and Written Test